CHANDRA OBSERVATIONS OF MRK 273: UNVEILING THE CENTRAL AGN AND THE EXTENDED HOT GAS HALO

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ABSTRACT

We report X-ray observations of the field containing the ultraluminous IRAS galaxy Mrk 273. The data were obtained using the ACIS-S3 instrument on board Chandra. The high resolution X-ray image, for the first time, reveals a compact hard X-ray nucleus in Mrk 273. Its position is coincident with the northern nucleus identified in the optical, infrared, radio and in molecular CO maps. Its X-ray energy distribution is well described by a heavily obscured AGN spectrum with an absorbed power-law plus a narrow Fe Kα emission line at 6.4 keV. The neutral hydrogen column density is about $4 \times 10^{23}\,\mathrm{cm}^{-2}$, implying an absorption-corrected X-ray luminosity (0.1–10 keV) for the nucleus of $L_{\mathrm{X}} \approx 6.5 \times 10^{43}\,\mathrm{erg\,s}^{-1}$ for $H_0 = 50\,\mathrm{km\,s}^{-1}\mathrm{Mpc}^{-1}$. The X-ray properties therefore firmly establishes the northern nucleus of Mrk 273 as a Seyfert 2 active galactic nucleus.

There are also bright soft X-ray clumps and diffuse soft X-ray emissions surrounding the central hard X-ray nucleus within the $10''$ of the nuclear region. Its spectrum can be fitted by a MEKAL thermal model with temperature of about 0.8 keV and high metallicity ($Z \sim 1.5 Z_{\odot}$) plus emission lines from α elements and ions. We find that a soft X-ray clump, about $4''$ (projected separation of about 4 kpc) southwest of the northern hard X-ray nucleus, is coincident with a nebula with strong [O III] λ5007 emissions. Further outside the central region, the Chandra observations reveal a very extended hot halo in

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Mrk 273. The X-ray halo encompasses the entire optical tidal tail and plume, with a projected diameter of about 108 kpc × 68 kpc. The total soft X-ray luminosity (0.1–2.4 keV) of the hot halo is $L_X \approx 1.9 \times 10^{41}$ erg s^{-1}, in the range of the soft X-ray luminosity of bright elliptical galaxies. The temperature of the hot gas is about 0.62 keV with a low metallicity ($Z \sim 0.1 Z_\odot$). We discuss the nature of the AGN in Mrk 273 and the implications of our results on the origin of X-ray halos in elliptical galaxies.

We also discuss the properties of Mrk 273x, a background AGN at redshift $z = 0.46$ in the Mrk 273 field. The AGN has an X-ray luminosity of $L_X \approx 2.43 \times 10^{44}$erg s^{-1} in the 0.5-10 keV band. Its X-ray properties resemble those of Seyfert 1 galaxies while its optical properties are similar to Seyfert 2 galaxies. Such mixed classifications in the optical and X-ray may be a challenge for the unification scheme of AGNs.

Subject headings: galaxies: Seyfert – galaxies: active – galaxies: individual (Mrk 273) – galaxies: interactions – galaxies: ISM – X-rays: galaxies

1. INTRODUCTION

Mrk 273 is an ultraluminous IRAS galaxy (ULIRG) at redshift $z = 0.0378$. It is a merging galaxy that shows a striking long tidal tail ($\sim 1'$) to the south, and a large tidal plume to the northeast (see Fig. 6). B-band images uncover diffuse clumps in the northeast plume. These plumes exhibit unusual optical spectra that are consistent with excitations by the shock plus precursor mechanism (Dopita & Sutherland 1995; Xia et al. 1999). Deep narrow-band Hα and [O III] λ5007 images (Armus et al. 1990) reveal filaments and arc structures in the northeast plume and patchy areas of ionized gas (extending tens of kpc) along the southern tidal tail. These observations of the extended structures provide evidence for shock excitations produced during merging.

The nuclear region of Mrk 273 is extremely complex. It shows double nuclei from both ground based images and HST optical (WFPC2), K-band (NICMOS) images (Knapen et al. 1998; Soifer et al. 2000; Carilli & Taylor 2000). The projected separation between the two nuclei in the K-band is 1.1″. The Hβ and [O III] λ5007 maps obtained using integral field spectroscopy of Mrk 273 show that there are two distinct emission regions separated by 4″ (Colina et al. 1999). The northeastern region coincides with the optical and K-band nuclei; it is strong in the Hβ emission but weak in the [O III] λ5007 emission, i.e., it exhibits LINER spectral characteristics. On the other hand, the southwestern region is dominated by diffuse [O III] λ5007 emission and Colina et al. (1999) identified this region as a Seyfert 2 nebula. Radio observations (Condon et al. 1991; Knapen et al. 1997) show that there are three components: the northern and southwestern components are coincident with the two K-band nuclei respectively while the southeastern component has a faint blue optical counterpart which was identified as a star-cluster by Scoville et al. (2000). High resolution radio continuum and neutral hydrogen 21cm absorption observations by MERLIN, Very Large Baseline Array, and Very Large Array (Cole et al. 1999; Carilli & Taylor 2000) reveal a gas disk associated with the northern nucleus. The disk has a diameter of $0.5''$ with an inclination angle of 53° and an average neutral hydrogen column density $\sim 1.7 \times 10^{22}\,\mathrm{cm}^{-2}$. Furthermore, the high resolution CO(2-1) map by Downes & Solomon (1998) uncovers a bright $0.35'' \times 0.2''$ CO core in the nuclear molecular disk of the northern nucleus of Mrk 273. This is the most luminous extreme compact starburst region for local ULIRGs with an infrared luminosity of $L_{\rm ir} \approx 6 \times 10^{11}\,\mathrm{L}_\odot$ and a molecular mass of $1 \times 10^9 M_\odot$. In short, the Mrk 273 nuclear region is very complex and it is not even clear how many different components there are, let alone whether various components are powered by AGN and/or starbursts.

X-ray observations provide an independent probe of the physical processes in merging galaxies such as Mrk 273. ASCA observation shows that there is a heavily obscured active nucleus in Mrk 273 (Turner et al. 1997, 1998; Iwasawa 1999). Hard X-ray emissions above 3 keV and a narrow 6.4 keV Fe Kα line were detected. An absorbed power-law model provides an acceptable fit to the spectrum although a reflection-dominated model can not be rejected either, based on the ASCA data (Iwasawa 1999). However, given that ASCA's spatial resolution is $2'$, the position of the AGN cannot be pinpointed; this is particularly serious because in the field of Mrk 273, ROSAT HRI images show that there is a background X-ray source (Mrk 273x at redshift $z = 0.46$) about $1.3'$ away (Xia et al. 1998). So the ASCA data include contributions from both Mrk 273 and Mrk 273x. The sub-arcsecond resolution and high-energy sensitivity of Chandra are therefore essential for understanding the nature of X-ray emissions in the Mrk 273 field.

Chandra observations are interesting for yet another important reason. Elliptical galaxies are known to have hot gas halos; however, the origin of the hot gas is still under debate (O'Sullivan et al. 2001; Sansom, Hibbard & Schweizer 2000). There is now firm evidence supporting the merger scenario for the formation of elliptical galaxies, through major and/or multiple merger (e.g., Hernquist et al. 1996; Borne 2000; Bekki 2001; Cui et al. 2001 and references therein). Based on the ASCA data for 4 ULIRGs (Mrk 231, Mrk 273, Arp 220 and NGC 6240), Iwasawa (1999) pointed out that the soft X-ray emissions of these ULIRGs are thermal with a temperature of $(0.5 - 1) \times 10^7$ K. Incorporating the extended morphology of soft X-ray emissions from NGC 6240, Arp 220 and NGC

3690 observed by ROSAT HRI, a thermal origin of the soft X-ray emission is acceptable. Furthermore, two-component fits to the soft X-ray data are better than one-component fits for these four ULIRGs and the low temperature component is more extended than the high temperature component (Iwasawa 1999). A plausible explanation is that the high temperature component is from central starbursts and/or AGNs while the more extended low-temperature component is provided by the shock-heated gas produced in mergers. A high-resolution soft X-ray image is therefore necessary to disentangle the X-ray emission from different parts of merging galaxies.

For the reasons described above, we have observed the Mrk 273 field using the ACIS-S3 instrument on Chandra; in this paper we report the results of these observations. Our focus is on Mrk 273 due to its implications for galaxy merging and formation, although we do briefly discuss the nature of the background source Mrk 273x (see § 5). The structure of this paper is as follows. In § 2, we describe the observations and data reduction. In § 3, we present the images for Mrk 273 in both the soft and hard X-ray band. These images reveal a compact hard X-ray nucleus and several soft X-ray clumps accompanied by a very extended hot halo. In § 4, we study the spatially-resolved spectral behaviors for the nuclear and extended X-ray emissions in Mrk 273. In § 5, we discuss the X-ray results for Mrk 273x from the Chandra observations. And finally in § 6, we summarize and discuss our results, particularly concerning the nature of the AGN in Mrk 273 and the connection to the origin of hot gas in elliptical galaxies. Throughout this paper, we use a Hubble constant of $H_0 = 50\,\mathrm{km\,s^{-1}Mpc^{-1}}$ and an Einstein-de Sitter ($\Omega_0 = 1$) cosmology although the latter has little influence on our results due to the low-redshift ($z \sim 0.0378$) of Mrk 273. At the redshift of Mrk 273, $1''$ corresponds to 1.03 kpc for the adopted cosmology.

2. OBSERVATIONS AND DATA REDUCTION

Mrk 273 and Mrk 273x were observed using the Chandra ACIS-S3 CCD chip on 19 April 2000, with a total exposure time of $\sim$ 47ks. The observation was performed in the very faint (VFAINT) mode with ACIS working at the focal temperature of -120° C. These two objects separated by $\sim 1.3'$ were positioned on the same chip with offsets of $65.5''$ and $37.6''$ from the ACIS-S aim-point, respectively.

The data were initially processed with the pipeline SDP version R4CU5UPD2, available when the data were first available to us; this pipeline has an astrometric error of about $3''$ [6]. The data used in this paper were reprocessed by the Chandra team using the new version

[6]http://asc.harvard.edu/mta/ASPECT/aspect_caveats_prior.html

of the software (SDP R4CU5UPD13.2) in January 2001. The most updated calibration files (such as ACIS QEU and gain map as well as observation-specific bad pixel lists) were used in the new data products. The data were also filtered to include only standard event grades 2, 3, 4 and 6 (see Chandra Proposer's Observatory Guide, 2000).

The improvements in the processing software and calibrations lead to an astrometric error of about $1.5''$. However, this position accuracy is still insufficient to align various nuclear components discovered in the optical, infrared and X-ray (see § 1). By carefully examining both the Chandra image and a WFPC2 HST image of Mrk 273, we found three point sources (shown in Fig. 2 as A [i.e., Mrk 273x], B, C) that are present in both sets of images. These point sources allow us to determine the astrometry in the Mrk 273 field to a much higher accuracy, $\sim 0.3''$; this accuracy is crucial to register the X-ray nuclear components with those in other wavebands.

The pre-processed and astrometrically-aligned data products were then analyzed with the standard CXC CIAO package (version 2.0). It begins with an inspection of bad aspect times and high background times. A background flare event was detected at the beginning of the observation; the corresponding time intervals with large background rate (i.e. 20% over the quiescent value) were thus removed, yielding an effective exposure time of ~ 41 ks in the energy range 0.3–10 keV. All the followup spatial and spectral analysis will be restricted to this energy band; the April 2000 release of the ACIS CCD calibration files (FEF) was used. As the standard CIAO tasks do not produce ARF and RMF for an extended source, we also made use of the contributed software, CALCRMF[7], for this purpose.

3. THE X-RAY IMAGE OF MRK 273

Fig. 1 shows the broad band (0.3–10keV) raw image of Mrk 273 and Mrk 273x at the full resolution ($0.49''$/pixel) of Chandra ACIS-S3. It is clear from Fig. 1 that the X-ray structure of Mrk 273 is complex with a bright nuclear region and very extended diffuse emission. Fig. 2 displays a true color image of Mrk 273, produced by a mosaic of three X-ray bands, namely, red: 0.3–1 keV, green: 1–3 keV and blue: 3–10 keV. Images in each of the three bands were adaptively smoothed using the CIAO task *csmooth*, at 3σ significant levels. The smoothing function we used is a scale-variable two-dimensional Gaussian with a maximum scale of 10 pixels ($\approx 5''$) to avoid inducing any over-smoothing effects. The inset at the bottom left corner is for the central $20'' \times 20''$ nuclear region. The complex X-ray

[7]http://hea-www.harvard.edu/~jcm/asc/dist/av/av104.tar

emission structures are clearer in this picture. It is obvious from Fig. 2 that the hard X-ray (3-10 keV) emission for Mrk 273 is compact (the white central region) while the soft X-ray emission (0.3–1 keV) consists of diffuse halos and bright complex structures. Furthermore, there are obvious intermediate X-ray band emissions surrounding the hard compact region shown as yellow in Fig. 2. We will discuss the possible origin for these emissions in § 6.

Fig. 3 shows more clearly the evolution of the nuclear region of Mrk 273 with the X-ray energy. As can be seen from this figure, the hard X-ray (> 3 keV) emission originates from a compact region while the soft X-ray emission is diffuse with some bright clumps. The dominant soft X-ray bright clumps are in the northeast and southwest. As X-rays become harder, the northeastern clumps become brighter while the southwestern clumps become fainter. This indicates that the northeastern clumps are harder than the southwestern clumps. Note that there is also a soft X-ray faint region in the northwest direction which can be clearly seen in the 0.6-0.8keV and 0.8-1.1keV panels.

3.1. THE NUCLEAR POSITION

Fig. 4 is an adaptively smoothed 0.3–1 keV soft X-ray image of the nuclear region. Four concentric circles indicate the $1'', 3'', 6''$ and $10''$ regions around the central nucleus. The square at the center of circles indicate the position of the compact hard X-ray source. It is clear that there are 4 soft X-ray bright clumps ,labelled as N, SE, SW1 and SW2, surrounding the hard X-ray source. The three plus signs in Fig. 4 indicate the three resolved radio components as given by Knapen et al. (1997). Table 1 lists the positions of the hard X-ray component and soft X-ray bright clumps together with the positions of the three radio components. The absence of soft X-ray emission in the hard X-ray compact region indicates that most soft X-ray emissions in the nucleus of Mrk 273 are absorbed.

It is obvious from Fig. 4 and Table 1 that the hard X-ray position is coincident with the northern radio component within the Chandra astrometric uncertainty ($\sim 0.3''$). This northern component also has counterparts in the K-band, mid-infrared and Hα (Hβ) narrow band images. The compact hard X-ray source is also likely to be embedded in a very dense, bright core of molecular gas (about $0.3'' \times 0.2''$) at the center of this nucleus (Downes & Solomon 1998). There is little doubt that the northern radio component of Mrk 273 hosts an AGN. The optical spectrum of this nucleus is of LINER-type (Colina et al. 1999; for more see § 5). On the other hand, the southwestern and southeastern radio components do not have any hard X-ray counterparts. The southwestern radio component is coincident with the southwestern K-band nucleus, which has been proposed to be the second nucleus of Mrk 273. However, the lack of hard X-ray emissions makes the interpretation less clear.

The left and right panels of Fig. 5 shows the 0.3–1 keV soft X-ray contours overlaying on [O III] λ5007 and Hα narrow band image for nuclear region of Mrk 273, respectively. The [O III] λ5007 and Hα narrow band image are obtained by the 2.16m telescope of Beijing Astronomical Observatory. The circle in the left and right panel of Fig. 5 indicates the hard X-ray position. It is clear from this figure that the southwestern soft X-ray bright clumps (SW1 and SW2) are coincident with [O III] λ5007 nebula and the hard X-ray source is within the northeastern Hα bright clump, which is identified as the northern nucleus in multi-wavelengths (see § 1). In fact, from Table 1 the angular distance between the hard X-ray position and the SW2 component is about $4''$, the same as the angular distance between the northern nucleus and southwestern 'Seyfert 2' nebula in Colina et al. (1999), which is dominated by the [O III] λ5007 line emission.

3.2. THE EXTENDED HOT GAS HALO

The adaptively smoothed 0.3–1 keV soft X-ray image of Mrk 273 is shown in the left panel of Fig. 6. The maximum smoothing scale is $5''$ (10 pixels) and the contours shown in the middle and right panels (see below) are 3, 5, 10, 20, 30, 50, 100 and 300σ significance levels respectively. Analysis indicates that most statistically significant photons are inside in the outer ellipse in the left panel of Fig. 6 and its major and minor radius are $52''$ and $33''$, respectively. These correspond to a physical diameter of 108 kpc $\times$ 68 kpc. This is the largest extended soft X-ray halo that has been identified in an ultraluminous IRAS galaxy. Furthermore, as we have shown, the high-resolution observation of Chandra allows us to compare fine structures with optical images at comparable resolution. The middle panel of Fig. 6 shows a deep R-band image of Mrk 273 (Armus et al. 1990) overlaid with the soft X-ray contours. It is obvious that the soft X-ray halo encompasses the whole Mrk 273 optical image, including the southern long tidal tail and northeast plume. In the right panel of Fig. 6, the soft X-ray contours are overlayed on an Hα narrow band image of Mrk 273 obtained using the 2.16m telescope of Beijing Astronomical Observatory. We can clearly see from this plot that the southern and northeastern soft X-ray structure are almost the same as the Hα structure. Curiously, while the X-ray extension seems agree well with the Hα extension, it shows a slight offset to the west of the optical tidal tail. This may be a natural consequence of the different behavior of collisionless stars and collisional gas (outflow) during galaxy merging as seen in Arp 299 (Hibbard & Yun 1999). We will return to the origin of the extended halo in § 6.2.

4. SPECTRAL ANALYSIS

Given the sub-arcsecond resolution of Chandra, we can perform not only global but also spatially-resolved spectral analysis. The latter is particularly important for understanding the relative contribution of the AGN/starburst contributions to the X-ray emission, and by implication the origin of hot gas in the descendents of mergers – elliptical galaxies. High spatial and spectral resolution of Chandra also allow one to separate, for the first time, the contributions to the hard X-ray emissions from Mrk 273 and Mrk 273x (see Fig. 1); this was impossible for ASCA due to its limited spatial resolution.

4.1. THE SPECTRUM OF THE CENTRAL $10''$ REGION

From Figs. 3 and 4 it is obvious that the 3-10 keV hard X-ray emission of Mrk 273 is mainly concentrated in the central compact region which shows little soft X-ray emission. Therefore, to study how the X-ray emissions evolve as one moves away from the central nucleus, we extract spectra for the four annulus within $10''$ region, as shown in Fig. 4, respectively. The spectra were binned so that each bin contains at least 15 counts. The results are shown in Fig. 7. It is clear from this figure that within the inner-most $1''$ region, most photons are hard with energy higher than 3 keV and there are few photons with energy below 0.8 keV. As the radius increases, the counts in soft X-ray band (0.3–2 keV) increase significantly, but the counts of hard X-ray photons have no substantial increase. More specifically, more than 80% hard X-ray photons are from the inner $1''$ region. and when the radius is increased to $3''$, the soft X-ray emission (0.3–2 keV) already dominates and there is no big difference in counts within the $6''$ and $10''$ circles. This result confirms the visual impression that the hard X-ray emission is mainly from the central compact region while the soft X-ray (below 2 keV) contribution is from a more extended area.

Fig. 8 is the spectrum for the whole $10''$ region of Mrk 273 from 0.3 to 8 keV, which is more reliably calibrated for the ACIS. The spectrum is clearly complex and consists of at least three components. At energies above 3 keV, there is a heavily absorbed power-law plus a narrow 6.4 keV Fe Kα line. The other two components are a less absorbed power-law and a MEKAL thermal plasma emission with many evident line features, in particular Fe L and Ne line complex, and other α elements emission lines (such as Mg Kα, Si Kα lines, OVII and OVIII lines). The parameters of the spectral fitting are given in Table 2 and the information for the emission lines is given in Table 3 and shown in Fig. 9. These components are discussed in more detail below.

It is clear from Fig. 8 and Table 2 that the central hard X-ray compact source has an absorbed power-law component and has a strong 6.4 keV Fe Kα emission line with an EW of 213 eV. The neutral hydrogen column density is $N_{\rm H} \approx 4.1 \times 10^{23}\,{\rm cm}^{-2}$ and the photon index is $\Gamma \approx 2.1$. The absorption-corrected X-ray luminosity is $L_{\rm X} \approx 6.5 \times 10^{43}\,{\rm erg\,s}^{-1}$, which is two orders of magnitude below the far-infrared luminosity of Mrk 273. It is worth comparing the value of neutral hydrogen column density determined by ISO/SWS mid-IR observation, which is $N_{\rm H} \approx 5 \times 10^{23}\,{\rm cm}^{-2}$ (Genzel et al. 1998). The similarity of the $N_{\rm H}$ values obtained using these independent methods gives strong support to this spectral model. These fitting results indicate that Mrk 273 contains an obscured moderate luminosity AGN. Incorporating the image information (§3.1), the northern nucleus of Mrk 273 is a Seyfert 2 nucleus with a hard X-ray compact source embedded in a bright compact molecular core.

On the other hand, the MEKAL thermal plasma model yields a satisfactory fit to the energy distribution of the hot gas surrounding the central nuclear region. Its temperature is about 0.8 keV, with $N_{\rm H} \approx 1.56 \times 10^{21}\,{\rm cm}^{-2}$ and a metallicity of about $1.5 Z_{\odot}$ (cf. Table 2). Also, there are remarkable Fe L, Ne line complexes, and Si Kα, Mg Kα, OVII and OVIII emission lines that are typical thermal excitation lines in the soft X-ray band. The absorption-corrected soft X-ray luminosity of the thermal emission is $L_{\rm X} \approx 2.6 \times 10^{41}\,{\rm erg\,s}^{-1}$. The properties of this soft X-ray thermal emission are very similar to the diffuse emission (excluding all the detected point sources) in the antenna galaxy NGC 4038/4039 (Fabbiano, Zezas & Murray 2001) and those in the prototypical starburst galaxy NGC 253 (Strickland et al. 2000). Therefore, the thermal bright soft X-ray emission within the central $10''$ of Mrk 273 is very likely due to massive starbursts.

There is also clearly a less absorbed second power-law component from the spectral fitting as shown in Table 2 and in Fig. 8 (the dashed line). We first identified it as the scattered light from the central nucleus since the fitting power-law index Γ ($\approx$1.9) is similar to that for the heavily absorbed power-law component. However, most of the scattered light below 1 keV from the AGN can not escape from the very dense core, due to the high neutral hydrogen column density in the nuclear region even outside the central torus ($N_{\rm H} \sim 1.7 \times 10^{22}\,{\rm cm}^{-2}$, Cole et al. 1999). This suggests that the second power-law component shown in Fig. 8 may have other contributions in addition to any directly scattered light from the central nucleus.

This component may be partly contributed to by the X-ray binaries (XRBs) or supernova remnants. It has become increasingly clear that they can make a significant contribution to the X-ray luminosity in starburst galaxies. Examples include NGC 253 (Strickland et al. 2000; Pietsch et al. 2001), M82 (Kaaret et al. 2001), interacting galaxies NGC 4038/4039 (Fibbiano et al. 2001), ULIRGs Arp 220 (Iwasawa et al. 2001) and perhaps even in the X-ray faint elliptical and S0 galaxies (Blanton et al. 2001). As Cappi et al. (1999) points out, the typical spectrum for the sum of low-mass XRBs and high-mass XRBs can be described by an exponentially cut-off power-law with index $0.5 < \Gamma < 2.5$ which seems to describe the observed Chandra spectrum for NGC 4038/4039. Therefore, it is plausible that the unresolved XRBs and supernova remnants give contributions to the less absorbed second power-law component in spectral fitting for the central $10''$ region of Mrk 273.

4.2. THE SPECTRUM OF THE EXTENDED HOT GAS HALO

The spectral fitting for the hot gas halo has been performed for the region between the outer ellipse and the inner circle shown in the left panel of Fig. 6 excluding all bright point sources (shown as small circles) in this region. Fig. 10 gives the MEKAL thermal model fitting and the fitting parameters are listed in Table 4. A thermal model with temperature of 0.62 keV, $N_{\rm H} \approx 3.0 \times 10^{20}\,{\rm cm}^{-2}$ and metallicity of about $0.1 Z_{\odot}$ yields an acceptable fit. The model dependent soft X-ray luminosity is $L_{\rm X} \approx 1.9 \times 10^{41}\,{\rm erg\,s}^{-1}$. Comparing with the central soft X-ray spectral properties, the temperature of the extended hot gas is clearly lower than that of the central starburst region. However, the difference is not large. The most striking difference between the central soft X-ray and the extended hot gas is the metallicity. The central starburst region has metallicity higher than the solar metallicity while the more extended hot gas outside seems to have a very low metallicity. We caution that we have modelled the halo as a single MEKAL thermal model; in reality, the gas may be clumpy and have complex temperature structures. A map with higher signal-to-noise ratio will be very useful to further strengthen our conclusions on metallicities. We briefly return to this important question of chemical enrichment in merging galaxies in §6.2.

5. MRK 273X

Based on its optical spectrum, Mrk 273x is classified as a Seyfert 2 galaxy. ROSAT observations indicate that it has an X-ray luminosity, $L_{\rm X} \approx 1.1 \times 10^{44}\,{\rm erg\,s}^{-1}$ in the 0.1-2.4 keV band, one of the highest in the soft X-ray band among Seyfert 2 galaxies (Xia et al. 1999). Borne et al. (1999) used HST I-band images of the Mrk 273 field to analyze the luminosity distribution of faint galaxies surrounding Mrk 273x. They suggest that Mrk 273x is the brightest elliptical galaxy in a relatively poor cluster. Hard X-ray observations have been carried out by ASCA and BeppoSax. However, due to their limited spatial resolution they can not resolve Mrk 273x from Mrk 273. Therefore the spectrum shown by Iwasawa (1999) is a composite spectrum of Mrk 273 and Mrk 273x. The high resolution and high-energy response of Chandra allow us to investigate the X-ray properties of Mrk 273 and Mrk 273x separately and also test the variability for both Mrk 273 and Mrk 273x.

5.1. THE SPECTRUM OF MRK 273X

As can be seen from Figs. 1 and 2, Mrk 273x is a bright X-ray point source. Figure 11 shows the observed Chandra spectrum of Mrk 273x from 0.3 to 8 keV. A power-law model with photon index $\Gamma = 1.66^{+0.15}_{-0.11}$ and $N_{\rm H} = 1.41^{+0.55}_{-0.50} \times 10^{21}\,{\rm cm}^{-2}$ plus a thermal component with temperature of $0.56^{+0.24}_{-0.24}$ keV and solar abundance give the best fit to the spectrum of Mrk 273x (the χ^2 per degree of freedom is 41.8/56). The absorption corrected X-ray luminosity in the 0.5-10 keV band is $L_{\rm X} \approx 2.43 \times 10^{44}\,{\rm erg\,s^{-1}}$. The luminosity of the thermal component is $L_{\rm X} \approx 6.0 \times 10^{42}\,{\rm erg\,s^{-1}}$, about 3% of the total X-ray luminosity of Mrk 273x. Since Mrk 273x is an elliptical galaxy from its de Vaucouleurs surface brightness profile (Borne et al. 1999), the thermal component of X-ray emission may naturally arise from the Mrk 273x host galaxy. From the spectral fitting, there is one significant emission line at 1.82 keV (Si XIII line) with EW$\approx$ 89 eV. In contrast, the Fe Kα emission line is not convincingly detected (the EW upper limit for a line at 6.4 keV is 30 eV at the 90% confidence level).

5.2. THE VARIABILITY OF MRK 273 AND MRK 273X

We reported that there was no significant variability for either Mrk 273 or Mrk 273x during ROSAT observations (Xia et al. 1998). The timing analysis for Mrk 273 and Mrk 273x based on the Chandra data alone also does not reveal any significant variability. In order to test for possible long term variabilities, we compile in Table 5 the X-ray fluxes of Mrk 273 and Mrk 273x in various X-ray bands from the literature.

From Table 5, the flux differences in the soft X-ray band (0.1-2.4 keV) are about 33%, 34% between ROSAT and Chandra observations over a span of 8 years for Mrk 273 and Mrk 273x, respectively. In the 0.5-10 keV band, the difference for the total flux of Mrk 273 and Mrk 273x between the Chandra observation in 2000 and the ASCA observation in 1996 is about 21%. In the 2-10 keV band, there are three reported observations for the total flux. While the Chandra and ASCA fluxes are within 30% of each other, the BeppoSax flux is lower by about a factor of 2 (Risaliti et al. 2000). To summarize, all the data except that from BeppoSax are consistent with no significant variability. However, much denser time sampling is required to firmly establish the variabilities of Mrk 273 and Mrk 273x.

5.3. THE NATURE OF MRK 273X

The X-ray properties of Mrk 273x can be compared with those of QSOs, Seyfert 1 and Seyfert 2 galaxies by ASCA and BeppoSax (e.g., Reeves & Turner, 2000; Pappa et al, 2001). Although Mrk 273x is classified optically as a Seyfert 2 galaxy, its X-ray properties are typical for a Seyfert 1 galaxy. Its high X-ray luminosity of $L_{\rm X} \approx 2.43 \times 10^{44}\,{\rm erg\,s^{-1}}$ falls into the regime of Seyfert 1 galaxies. Furthermore, similar to many Seyfert 1 galaxies, it is dominated by a power-law spectrum with $\Gamma \approx 1.68$, there is no cutoff at low energies and the Fe Kα line is not detected.

Objects with Seyfert 2's optical spectrum but with Seyfert 1's properties in the X-ray have been reported (for example NGC3147, Ptak et al. 1996; NGC7590, Bassani et al. 1999; NGC4698, Pappa et al, 2001; NGC7679, della Ceca et al, 2001). Mrk 273x is another such example, although the X-ray luminosity of Mrk 273x and the ratio of the hard X-ray luminosity (in the 2-10 keV band) to the OIII luminosity, $f_{\rm HX}/f_{\rm OIII}$, are one of the highest even among this subclass of AGNs (the $f_{\rm HX}/f_{\rm OIII}$ ratio for Mrk 273x is 86). Given that these sources have weak or no Fe Kα detection and high $f_{\rm HX}/f_{\rm OIII}$ ratios, they could not be Compton thick objects (with $N_{\rm H} > 10^{24}\,{\rm cm^{-2}}$) because for such objects, the EW of Fe Kα is well above 1 keV and the $f_{\rm HX}/f_{\rm OIII}$ ratio is less than 1 (Gilli et al. 1999). Therefore, the power-law spectrum of this type of object is not from reflection, but could be due to the lack of intrinsic absorption. The most straightforward explanation for this type of object is that it lacks broad line regions and the Seyfert 2 optical spectrum is intrinsic, but not due to heavy absorption (Pappa et al. 2001). The existence of such objects challenges the standard AGN unification model. Moreover, Mrk273x has a very high X-ray to optical B-band flux ratio (≈ 7, Xia et al. 1998), which is only achieved by BL Lacertae objects (Stocke et al. 1991). The strong optical emission lines and the lack of dramatic X-ray variability (see §5.2), however, do not support Mrk 273x being a BL Lacertae object. Therefore, Mrk 273x still remains a mysterious object that warrant further studies.

6. SUMMARY AND DISCUSSION

Compared with earlier satellites, the Chandra ACIS-S3 observation of the Mrk 273 field unveils unprecedented details of the X-ray emissions in the merging galaxy Mrk 273.

These observations raise a number of important questions, which we will discuss below.

6.1. THE NUCLEAR REGION OF MRK 273

Multi-wavelength high resolution imagings for the nuclear region of Mrk 273 reveal intricate and puzzling details of the heavily dust-obscured nuclear region of Mrk 273 (see §1 and §3.1). Some components in one waveband have no clear counterparts in other wavebands. The northern K band putative nucleus has radio, mid-infrared and Hα narrow band counterparts. Combined with the fact that there is a bright molecular core at the center, this nucleus most likely hosts a central AGN. This is further supported by the Chandra X-ray observations, where we have identified a hard X-ray source coincident with this northern nucleus within the astrometric uncertainty. The X-ray spectrum of the hard X-ray source is typical for Seyfert 2 galaxies.

The 'contradiction' is from the comparison with the integral field spectroscopy of Mrk 273 by Colina et al. (1999) from which the northern nucleus of Mrk 273 has a LINER optical spectrum. However, as suggested by Terashima et al. (2000), a LINER 1 spectrum can also be produced by photoionizations due to hard photons from a low-luminosity AGN. The northern nucleus of Mrk 273 may be similar, although in this case, the low-luminosity is not intrinsic but due to the heavy attenuation of gas. The high neutral hydrogen column-density ($N_{\rm H} \sim 4.1 \times 10^{23}\,{\rm cm}^{-2}$) implies that the soft X-ray photons could not escape from the central region, and thus the photoionizations can only be due to hard X-ray photons from the Mrk 273 northern nucleus. Therefore, a LINER 1 spectrum can also be a result of photoionizations by hard photons from a high-luminosity AGN that is heavily absorbed by a dense neutral gas. This mechanism may be common for ULIRGs where both central AGNs and large amount of neutral gas are present in these merging galaxies.

On the other hand, the southwestern soft X-ray clumps are coincident with a bright [O III] λ5007 nebula with angular distance of $4''$ (projected separation of about 4 kpc) from the northern nucleus (see Fig. 5). This region has a spectrum dominated by the [O III] λ5007 line emission and is classified as a Seyfert 2 nebula by Colina et al. (1999). The northern nucleus has an associated extended gas disk with an inclination angle of 53° (Carilli & Taylor 2000). The CO molecular disk has a similar inclination angle from the velocity map of Downes & Solomon (1998). This orientation, combined with the relative positions of the hard X-ray compact source, bright [O III] λ5007 nebula, southwestern radio emission (Cole et al. 1999) as shown in Figs. 4 and 5 and the narrow profile of [O III] λ5007 line (FWHM $< 260{\rm km\,s^{-1}}$) (Colina et al. 1999), suggest that the southwestern bright [O III] λ5007 nebula may be an extended narrow line region: the [O III] λ5007 emission region may reside in an ionization cone centered on the hard X-ray source. This geometry and the strong correlation between the soft X-ray clumps and the high excitation (e.g. [O III] λ5007) optical line emission is similar to the case in the nearby Seyfert 2 galaxy NGC 1068 (Young et al. 2001). Therefore, the photoionization source for both the [O III] λ5007 and soft X-ray may be the central AGN associated with the northern nucleus. It is, however, still possible that the excitation can be produced by shocks occurring in galaxy merging (Xia et al. 1999).

6.2. THE ORIGIN OF HOT GAS HALO OF MERGING GALAXY

Figs. 2 and 4 clearly show that the soft X-ray (0.3–2 keV) image of Mrk 273 is complex with several bright clumps surrounding a hard X-ray compact nucleus, irregular structure along the direction of southern tidal tail and faint structure along the northern plume. It extends beyond the optical emission region with a projected diameter of about 108 kpc × 68 kpc. A MEKAL thermal model with temperature of 0.62 keV and metallicity of about $0.1Z_{\odot}$ provides the best fit. The model-dependent soft X-ray luminosity of this hot gas halo is $L_{\rm X} \approx 1.9 \times 10^{41}\,{\rm erg\,s^{-1}}$. From Tables 2 and 4, the hot gas properties in the central starburst region and the faint very extended halo are very different. The very low metallicity implies that the diffuse hot gas halo has not yet been chemically contaminated by stellar processes such as superwinds which are expected to carry a substantial amount of heavy metals (Heckman 2001).

The temperature and luminosity of this very extended hot gas halo are in the range of bright elliptical galaxies (Brighenti & Mathews 1997) and a sample of merging galaxies studied by Read & Ponman (1998). The X-ray data therefore suggest that merging can produce hot halos that resemble those seen in elliptical galaxies, which adds another piece of evidence for elliptical galaxy formation via mergers. The low-metallicity of the gas indicates that the cooling time of the gas may have been under-estimated by a factor of a few (e.g., Fig. 9-9 in Binney & Tremaine 1987) since many previous studies assumed solar-metallicities (e.g., Sarazin 1990). This hot gas may remain X-ray luminous for more than $\sim$ 1 Gyr, long after the stellar components at the center have relaxed dynamically. The low metallicity, although somewhat uncertain, suggests that part of the X-ray emission in elliptical galaxies may be due to secondary infalls in the pre-merger (group) environment (e.g., Brighenti & Mathews 1998, 1999), which have not yet been contaminated by the central starbursts. This is also consistent with the recent work by Bekki (2001) who studied multiple galaxy mergers using numerical simulations. He showed that metals produced and ejected in central star formation regions are mostly mixed with the local interstellar medium. Consequently, the ISM of the outer part of the merger is less metal-enriched. The radial gradient in metallicity seen in Mrk 273 is certainly consistent with the picture, where the $10''$ central region has a metallicity ($Z \sim 1.5Z_{\odot}$) while the very extended hot gas halo has a much lower metallicity ($Z \sim 0.1Z_{\odot}$). We caution, however, that the star formation treatment in numerical simulations is not realistic in the sense that the multi-phase medium nature of the interstellar medium is not properly taken into account. As a consequence of this inadequacy, the region that are chemically enriched may be under-estimated.

To conclude, the high resolution observation of the Mrk 273 field by Chandra yielded important results for both Mrk 273 and Mrk 273x. For Mrk 273x, Chandra observation confirm that its X-ray properties are similar to Seyfert 1 galaxies while it is classified as a Seyfert 2 galaxy optically. For Mrk 273, where our primary interests lie, Chandra observation, for the first time, reveals a compact hard X-ray nucleus inside a much more extended halo. Although the nuclear region of Mrk 273 is complex, it is a typical Seyfert 2 nucleus with extended narrow line region. The high temperature and high-metallicity thermal emission component from the spectral fitting are obviously from the starburst region, while the much more extended hot gas halo has a much lower metallicity and may have a different origin. The data provide further support for the evolutionary connection between galaxy merging and elliptical galaxies. More high-resolution deep images of merging galaxies at various stages will be very useful for providing further clues of X-ray halos in merging galaxies and their descendents, elliptical galaxies.

We are grateful to the CXC team for assistance in observations and data reduction. We also thank Drs. H.J. Mo, A. Pedlar, J. Skelton, Y. Gao, M.S. Yun, X.P. Wu, D. Wang, T.G. Wang and X.W. Liu for advice and helpful discussions. Thanks are also due to Dr. Z.J. Jiang for help in the data reduction. This project was supported by the NSF of China and NKBRSF G19990754. SM gratefully acknowledges a travel grant awarded by the NSF of China.

REFERENCES

Armus, L., Heckman, T. M., & Miley, G. K. 1990, ApJ, 364, 471

Bassani, L., Dadina, M., Maiolino, R., Salvati, M., Risaliti, G., della Ceca, R., Matt, G., & Zamorani, G. 1999, ApJS, 121, 473

Binney, J. J., Tremaine, S. 1987, Galactic Dynamics (Princeton: Princeton University Press), p. 580

Bekki, K. 2001, ApJ, 546, 189

Blanton, E. L., Sarazin, C. L., & Irwin, J. A. 2001, ApJ, in press (astro-ph/0012481)

Borne, K.D., Colina, L., Bushouse, H., & Lucas, R.A. 1999, ApJ, 527, 554

Cappi, M., et al. 1999, A&A, 350, 777

Carilli, C. L., & Taylor, G. B. 2000, ApJ, 532, L95

Cole, G. H. J., Pedlar, A., Holloway, A. J., & Mundell, C. G. 1999, MNRAS, 310, 1033

Colina, L., Arribas, S., & Borne, K. 1999, ApJL, 527, L13

Condon, J. J., Huang, Z.-P., Yin Q. F., & Thuan, T. X. 1991, ApJ, 278, 65

Cui, J., Xia, X.-Y., Deng, Z.-G., Mao, S., Zou, Z.L. 2001, AJ, in press (astro-ph/0104296)

della Ceca, R., Pellegrini, S., Bassani, L., Beckmann, V., Cappi, M., Palumbo, G.G.C., Trinchieri, G., & Wolter, A. 2001, A&A in press (astro-ph/0106444)

Dopita, M. A., & Sutherland, S. 1995, ApJ, 455, 468

Downes, D., & Solomon, P. M. 1998, ApJ, 507, 615

Fabbiano, G., Zezas, A., & Murry, S. S. 2001, ApJ, in press (astro-ph/0102256)

Genzel, R., et al. 1998, ApJ, 498, 579

Gilli, R., Comastri, A., Brunetti, G., & Setti, G. 1999, NewA, 4, 45

Heckman, T. M. 2001 in "Gas & Galaxy Evolution", in press (astro-ph/0009075)

Hibbard, J. E., & Yun, M. S. 1999, AJ, 118, 162

Iwasawa, K. 1999, MNRAS, 302, 96

Iwasawa, K., Matt, G., Guainazzi, M., & Fabian, A. C. 2001, MNRAS, in press (astro-ph/0103417)

Kaaret, P., et al. 2001, MNRAS, 321, L29

Knapen, J. H., Laine, S., Yates, J. A., Robinson, A., Richards, A. M. S., Doyon, R., & Nadeau D. 1997, ApJ, 490, L29

O'Sullivan, E., Forbes, D. A., & Ponman, T. J. 2001, MNRAS in press, (astro-ph/0101271)

Pappa, A., Georgantopoulos, I., Stewart, G.C., & Zezas, A.L. MNRAS in press (astro-ph/0104061)

Pietsch, W., et al. 2001, A&A, 365, L174

Ptak, A., Yaqoob, T., Serlemitsos, P.J., & Kunieda, H. 1996, ApJ, 459, 542

Risaliti, G., Gill, R., Maiolino, R., & Salvati, M. 2000, A&A 357, 13

Read, A.M., & Ponman, T. J. 1998, MNRAS, 297, 143

Reeves J.N., & Turner M.J.L. 2000, MNRAS, 316, 234

Sansom, A.E., Hibbard, J.E., Schweizer F. 2000, 120, 1946

Sarazin, C. L. 1990, in The Interstellar Medium in Galaxies, eds. H.A. Thronson, & J. M. Shull (Dordrecht: Kluwer), 201

Sarazin, C. L., Irwin, J. A., & Bregman, J. N. 2000, ApJ, 544, L101

Scoville, N. Z., Evans, A. S., Thompson, R., Rieke, M., Hines, D. C., Low, F. J., Dinshaw, N., Surace, J. A., & Armus, L. 2000, AJ, 119, 991

Soifer, B. T. et al. 2000, AJ, 119, 509

Stocke, J.T., et al. 1991, ApJS, 76, 813

Strickland, D. K., Heckman, T. M., Weaver, K. A., & Dahlem, M. 2000, AJ, 120, 2965

Terashima, Y., Ho, L. C., & Ptak, A. F. 2000, ApJ, 539, 161

Turner, T. J., George, I. M., Nandra, K., & Mushotzky, R. F. 1997, ApJS, 113, 23

Turner, T. J., George, I. M., Nandra, K., & Mushotzky, R. F. 1998, ApJ, 493, 91

Xia, X.-Y., Boller, Th., Wu, H., Deng, Z.-G., Gao, Y., Zou, Z.-L., Mao, S., & Börner, G. 1998, ApJ, 496, L9; erratum, ApJ, 1998, 507, L99

Xia, X.-Y., Mao, S., Wu, H., Liu, X.-W.; Gao, Y., Deng, Z.-G., Zou, Z.-L. 1999, ApJ, 524, 746

Young, A. J., Wilson, A. S., & Shopbell, P. L. 2001, ApJ, in press (astro-ph/0104027)

Fig. 1.— Broad-band (0.3–10keV) raw image of Mrk 273 and Mrk 273x at full resolution ($0.49''$/pixel) of Chandra ACIS-S3. North is up and east is to the left. The northeast bright source is Mrk 273x. The field of view is $3.7' \times 6.25'$.

Fig. 2.— Adaptively smoothed true color image of Mrk 273, with a maximum smoothing scale of 10 pixels ($\approx 5''$). The image is produced by a mosaic of three X-ray bands, namely the 0.3–1 keV (red), 1-3 keV (green) and 3-10 keV (blue) energy ranges. The inset shows a magnified view of the central region. Three point sources (labelled as A, B and C) are used to register the Chandra astrometry (see §2). Object A is Mrk 273x.

Fig. 3.— The central $24'' \times 24''$ region of Mrk 273 in six X-ray bands; the energy range is indicated at the bottom left of each panel. Notice how different regions evolve as the energy band changes. It is apparent that the hard X-ray component is relatively compact.

Fig. 4.— The soft X-ray image (0.3–1 keV) of the nuclear region of Mrk 273. The square is for the hard X-ray position and three crosses are for the three resolved radio emission components (Knapen et al. 1997). The coordinates for all these components are shown at Table 1. The hard X-ray position is coincident with the northern radio component within the uncertainty of the Chandra astrometry; this component also has counterparts in the K-band, mid-infrared and molecular CO maps. The spectra for the emission contained within the four circles are shown in Fig. 7.

Fig. 5.— The left panel shows the [O III] λ5007 image overlaid by soft X-ray (0.3–1 KeV) contours while the right panel shows the Hα image overlaid by soft X-ray (0.3–1 KeV) contours for nuclear region of Mrk 273. In both panels, the center of the circle indicates the hard X-ray position.

Fig. 6.— Adaptively smoothed X-ray image in the 0.3–1 keV energy range of Mrk 273. The maximum smoothing scale is $5''$. The left panel is a smoothed image. Notice that most photons must be included in the outer ellipse which has a size $52'' \times 33''$ and a position angle of 13°. The spectrum for the extended hot gas halo is extracted for the region between the outer ellipse and the inner circle, and is shown in Fig. 10. The middle and right panels are the R band deep image and Hα narrow band image of Mrk 273 overlaid by the Chandra soft X-ray contours at 3, 5, 10, 20, 30, 50,100 and 300σ, respectively. It is clear from these plots that the hot gas halo of Mrk 273 encompasses both the long tidal tail to the south and the plume to the northeast. Notice that the soft X-ray has almost the same structure as Hα in the southern and northeastern direction, but offset with southern optical tidal tail.

Fig. 7.— The spectra for the central $1'', 3'', 6''$ and $10''$ nuclear regions.

Fig. 8.— The 0.3–8 keV spectrum of the central 10″ region of Mrk 273. The spectrum is fitted well with the superposition of a heavily absorbed power-law, a less absorbed power-law, a thermal MEKAL component plus 6.4 keV Fe Kα, Fe L, Ne line complex, and other α elements emission lines. The fitting parameters are shown in Tables 2-3.

Fig. 9.— The ratio of the data to the model continuum, highlighting the features due to emission lines.

Fig. 10.— The 0.3–2keV spectrum for the extended hot gas halo for the region between the outer ellipse and the inner circle in the left panel of Fig. 4. A MEKAL model with temperature of 0.62 keV and metallicity of about $0.1Z_{\odot}$ provides a satisfactory fit. The fitting parameters are given in Table 4.

Fig. 11.— The observed 0.3–8 keV spectrum for Mrk 273x. The spectrum is fitted well with the superposition of an absorbed power-law, a thermal MEKAL component and a line emission at 1.82keV (see §5.1 for the fitting parameters).

Table 1. Positions of the nuclear hard X-ray source, soft X-ray clumps and radio components

Name	RA	DEC	Separation
Hard X-ray	13:44:42.12	55:53:12.9	0.28″
Clump N	13:44:42.11	55:53:14.4	1.22″
Clump SE	13:44:42.33	55:53:11.5	2.46″
Clump SW1	13:44:41.93	55:53:11.0	2.69″
Clump SW2	13:44:41.70	55:53:11.5	3.90″
Radio N	13:44:42.1171	55:53:13.182	0″
Radio SE	13:44:42.1677	55:53:12.496	0.81″
Radio SW	13:44:42.0372	55:53:12.144	1.24″

Note. — Chandra corrected positions for various nuclear components of Mrk 273 together with the the radio nuclear components from Knapen et al. (1997). The Chandra astrometry has been corrected using the three point sources shown in Fig. 2 and has an uncertainty of $\sim 0.3''$ (the Chandra components are shown in Fig. 4). The radio astrometry has an error of 2 mas for the N and SE components and 27 mas for the SW component (see Knapen et al. 1997, Table 2). The K band northern nucleus is at the same position as the radio northern (N) nucleus and the southwest K band nucleus is about $1''$ to the northern nucleus, nearly coincident with the radio SW component. Column 1 is the name of the Chandra or radio components. The second and third columns are the RA and DEC for the components while column 4 is the separation between each component and the northern (N) radio component.

Table 2. Spectral fits to the central 10″ region

MEKAL[a]			PL_2[b]		PL_1[c]+ Line					
N_H [10^{21} cm^{-2}]	kT [keV]	Z [$Z_\odot$]	N_H [10^{21} cm^{-2}]	Γ_1	N_H [10^{23} cm^{-2}]	Γ_2	E_{line} [keV]	σ [keV]	EW [eV]	χ^2_ν
$1.56^{+1.29}_{-1.56}$	$0.77^{+0.09}_{-0.04}$	$1.48^{+3.10}_{-0.25}$	$0.69^{+0.31}_{-0.22}$	$1.94^{+0.31}_{-0.28}$	$4.13^{+0.42}_{-0.58}$	$2.10^{+0.22}_{-0.25}$	$6.37^{+0.04}_{-0.05}$	$2.9^{+5.1}_{-2.9}$	213^{+110}_{-94}	0.97

[a]Emission measure as absorption corrected luminosity, $L_{\rm MEKAL}(0.1-10\,{\rm keV}) = 2.6^{+0.32}_{-0.37}\times10^{41}\,{\rm erg\,s^{-1}}$.

[b]Emission measure as absorption corrected luminosity, $L_{\rm PL_2}(0.1-10\,{\rm keV}) = 1.5^{+0.40}_{-0.62}\times10^{42}\,{\rm erg\,s^{-1}}$.

[c]Emission measure as absorption corrected luminosity, $L_{\rm PL_1}(0.1-10\,{\rm keV}) = 6.5^{+1.8}_{-2.8}\times10^{43}\,{\rm erg\,s^{-1}}$.

Note. — Model: Absorption × MEKAL(kT, Z) + Absorption × PL(Γ_2) + Absotption × [PL(Γ_1) + Line], where MEKAL is for the Mewe, Kaastra & Liedahl thermal plasma model, PL_1 & PL_2 are for the two power-law models, and the emission lines have Gaussian profiles.

Table 3. Line detections from the spectrum of the central 10″ region

Rest energy [keV]	Line Flux [10^{-6} phs cm^{-2} s^{-1}]	EW [eV]	Line
$6.37^{+0.04}_{-0.05}$	$6.2^{+3.2}_{-3.0}$	213	Fe Kα
$5.81^{+0.09}_{-0.05}$	$2.7^{+2.3}_{-2.3}$	126	?
$5.47^{+0.07}_{-0.16}$	$0.4^{+1.9}_{-1.9}$	100	?
$3.88^{+0.05}_{-0.06}$	$0.5^{+0.6}_{-0.5}$	110	Ca XIX
$3.55^{+0.05}_{-0.06}$	$0.6^{+0.5}_{-0.6}$	195	?
$1.91^{+0.05}_{-0.04}$	$1.0^{+0.4}_{-0.6}$	110	Si Kα
$1.49^{+0.05}_{-0.04}$	$1.0^{+0.4}_{-0.7}$	75	Mg Kα
0.76-1.26[a]	-	-	Fe & Ni complex
$0.69^{+0.04}_{-0.04}$	$2.5^{+1.3}_{-1.0}$	65	O VIII
$0.57^{+0.17}_{-0.19}$	$1.7^{+2.0}_{-1.2}$	34	O VII

[a]Thermal emission bump with many unresolved lines.

Table 4. Spectral parameters for the extended hot halo

Model	$N_{\rm H}$ [10^{21} cm^{-2}]	kT [keV]	Z [$Z_\odot$]	χ^2/d.o.f	$A_{\rm MEKAL}$[a] [10^{-5}]	$L_{\rm X}$[b] [10^{41}erg s^{-1}]
MEKAL	$0.30^{+0.71}_{-0.30}$	$0.62^{+0.07}_{-0.13}$	$0.11^{+0.10}_{-0.06}$	20/27	$3.8^{+1.4}_{-1.9}$	$1.9^{+0.5}_{-0.6}$

[a]The model normalization, $A_{\rm MEKAL}$, is defined as $10^{-14}\int n_{\rm e}n_{\rm H}dV/(4\pi(1+z)^2D_A^2)$, where $n_{\rm e}$ is the electron number density (cm^{-3}), $n_{\rm H}$ is the hydrogen number density (cm^{-3}) and D_A is the angular diameter distance to the source in units of cm.

[b]The luminosity in the 0.1-2.4 keV band, corrected for both the Galactic and intrinsic absorptions.

Table 5. X-ray fluxes in units of 10^{-13}erg s^{-1} cm^2 for Mrk 273 and Mrk 273x[a]

Source	f(0.1-2.4keV)	f(2-10 keV)	f(0.5-10 keV)	Instrument	time
Mrk 273	1.25			ROSAT	1992
Mrk 273	0.94	7.93	8.72	Chandra	2000
Mrk 273x	1.10			ROSAT	1992
Mrk 273x	0.82	1.19	1.85	Chandra	2000
Mrk 273+Mrk 273x	2.35			ROSAT	1992
Mrk 273+Mrk 273x	1.7[b]	7.0	8.7	ASCA	1996
Mrk 273+Mrk 273x		3.50		BeppoSax	1998
Mrk 273+Mrk 273x	1.76	9.12	10.57	Chandra	2000

[a]The flux by ROSAT, ASCA and BeppoSax are from Xia et al. (1998), Iwasawa (1999) and Risaliti et al. (2000), respectively. Notice that for ASCA and BeppoSax observations only the total fluxes of Mrk 273 and Mrk 273x are given as they do not resolve these two sources.

[b]This flux is in the 0.5-2.0 keV band from Iwasawa (1999).